XVII. *On the Physical Structure of the Old Red Sandstone of the County of Waterford, considered with relation to Cleavage, Joint Surfaces, and Faults.*

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1. *Description of the District.*

In a paper published by me in the Philosophical Magazine*, I have stated my views in relation to cleavage structure of rocks, considered in connexion with the distortion of fossils, and arrived at the following results:—

1st. That the cleavage is in planes perpendicular to the lines of maximum pressure.

2nd. That the distortion of fossils, in any plane of bedding, depends on the angle made with the plane of cleavage, by the plane of bedding considered; increasing with that angle, according to a law, which I have defined in the paper itself.

During the course of the past summer (1857), I was enabled to study the physical structure of the Old Red Sandstone conglomerate of the county of Waterford; a rock eminently unsuited to the production of cleavage, or indeed, any other phenomena, by the influence of polar forces; and, in the course of my observations, I arrived at facts which appear to me to be inexplicable on any other than a mechanical theory. As the facts themselves are worthy of record, whatever opinion may be formed of the inferences I have deduced from them, and as the observations on which they depend (345) are more numerous than usual, and, as I believe, carefully made, I have felt myself justified in bringing them under the notice of the Royal Society, and thus placing them on record.

The Old Red Sandstone conglomerate of the South-east of the county of Waterford extends in an E.N.E. and W.S.W. direction, from Creadan Head, Waterford Harbour, to Brownstown Head, east of Tramore Bay, a distance of $7\frac{3}{4}$ miles; and in a perpendicular direction, its greatest breadth is about $3\frac{1}{4}$ miles. The average bearing, or strike of the beds of which it is composed, is parallel to the line of greatest length, and it has throughout a dip or inclination towards the sea, ranging from 5° to 20°. Its lowest portion consists of some 200 feet of solid conglomerate, surmounted by varying beds of red sandstone and shale of every degree of mechanical fineness and subdivision. The

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observations of cleavage, joint, and fault planes here recorded, are confined to the solid conglomerate itself, as this rock seemed to me, to offer a sort of *experimentum crucis* between the polar and mechanical theories of cleavage and joints.

This conglomerate is composed of numerous rounded pebbles, principally of quartz, with a few of slate, and granite containing white mica, similar to that of the granites of the main chain between Dublin and New Ross (70 miles); the quartz pebbles being generally from 4 to 6 inches in diameter, the whole cemented together by a paste, rarely calcareous, containing abundance of red peroxide of iron, which gives its characteristic colour and name to the entire rock.

About the centre of the coast line between Creadan and Brownstown Heads, is the promontory of Red Head, forming the western entrance into Waterford Harbour, and remarkable as being the central point of the geological elevation of the whole district, inasmuch as the faults to the eastward of Red Head are accompanied by downthrows to the east, while the faults to the westward of Red Head are accompanied by downthrows to the west. There are three distinct kinds of physical planes observable in the Old Red Sandstone conglomerate of this district, on each of which it is necessary to make some remarks. These planes are—1st. Faults; 2nd. Joints; 3rd. Cleavage Planes.

2. *Faults.*

A fault is a plane of division in a rock, along which the separated portions of rock have slipped, either vertically or horizontally, or both; the amount of vertical dislocation is the *downthrow*, and the amount of horizontal displacement is the *heave* of the fault. I determined the position, strike, inclination, and generally the downthrow of twenty faults, which are easily reducible to several systems, very well marked, and having a close connexion with the corresponding systems of joint planes and cleavage planes to be described presently. As some of these systems of faults are at right angles to others, I shall group them together according to their natural relations, as follows:—

System A.

No.	Bearing.	Dip.	Downthrow.	Locality.
1.	E. 10° N.	55° N.	10 feet North.	Portnashrughaun.
2.	E. 5 N.	66 N.	North.	Beenlea, West.
Mean = 7° 30′ North of East (Magnetic).				

System C.

No.	Bearing.	Dip.	Downthrow.	Locality.
1.	N. 10° W.	70° E.	50 feet East.	East side of Red Head.
2.	N. 5 W.	90	6 feet West.	Bishop's Cove.
3.	N. 0 W.	75 W.	20 feet West.	Stony Cove.
4.	N. 0 W.	......	....	Kilmaleague.
Mean = 3° 45′ West of North (Magnetic).				

System A'.

No.	Bearing.	Dip.	Downthrow.	Locality.
1.	E. 35° N.	74° N.	10 feet North.	Lady Waterford's Rocks.
2.	E. 35 N.	75 N.	3 feet North.	Lady Waterford's Rocks.
3.	E. 35 N.	90	3 feet North.	Lady Waterford's Rocks.
4.	E. 35 N.	65 N.	1 foot North.	Portnashrughaun.
5.	E. 35 N.	90	5 feet North.	Portnashrughaun.
6.	E. 30 N.	N.	104 feet North.	Old Ship's Cove.
7.	E. 35 N.	80 N.	4 feet North.	East of Swiny Head.
8.	E. 35 N.	60 N.	75 feet North.	Stony Cove.
Mean =34° 22' North of East (Magnetic).				

System C'.

No.	Bearing.	Dip.	Downthrow.	Locality.
1.	N. 35° W.	53° W.	8 feet West.	Centre of Red Head.
2*.	N. 32 W.	66 E.	3 feet West.	Portnashrughaun.
3.	N. 30 W.	75 W.	6 feet West.	Pusnahooan.
4.	N. 35 W.	60 E.	10 feet East.	East of Cathedral Rocks.
5.	N. 35 W.	80 W.	2 feet West.	Creadan Bay.
Mean =33° 24' West of North (Magnetic).				

There is one other fault, not referable to any of the foregoing systems; it occurs at Rathmoylan Cove; bearing, N. 40° E.; dip, 70° E.; downthrow, 1 foot eastward: although it appears as an exception at first sight, it will be seen from the discussion of the directions of the joint and cleavage planes, that this fault really belongs to another system of planes which is well developed in other parts of the district. Roughly speaking, it appears that the systems A and C, A' and C', have bearings nearly at right angles to each other; the angle between the first two systems being, from East to North, 93° 45', and the angle between the systems A' and C' being 89° 2'.

The most important of the systems of faults, estimated by the amount of dislocation caused by them, are the systems C and A'; the former containing the well-marked downthrow of 50 feet east of Red Head, and the latter containing the two greatest faults in the entire district, viz. 104 feet at Old Ship's Cove, and 75 feet at Stony Cove, both downthrows to the west. If we had no other evidence of the physical structure of the conglomerate than is supplied by the foregoing systems of faults, we should be entitled to conclude that two systems of elevating forces had acted, either simultaneously or in succession, to raise the conglomerate beds to their present dip, and dislocate them along the planes described. The planes of the elevating forces were probably vertical planes, nearly in the azimuths of 5° West of North, and 33° West of North (both magnetic bearings). I have reason to believe that the conjugate system (A, C) has been principally concerned in imparting to the mass of conglomerate its inner or latent structure, which

* This is a reversed fault.

I shall presently describe under the name of cleavage, and that it was the first system of forces that acted upon the coarse shingle of the Old Red Sandstone shore after its deposition; at the same time there is reason to think that the conjugate system (A′, C′) was the most powerful of the two systems of forces. Both were concerned in producing the elevation of the beds, which have an average strike of E. 10° 46′ N., and an average dip of 13° 42′ S. The strike of the beds is thus seen to be intermediate between the systems A and A′, but lying nearest the former, which I conceive to have acted first in order of time.

Throughout this paper I shall speak of planes, or faults, having rectangular bearings, as forming a conjugate system; assuming the well-known mechanical principles established by CAUCHY, who has shown that in any system of molecules affected with internal tensions, there is at each point a system of three orthogonal planes, corresponding with the three principal planes of the ellipsoid of tension, whose centre is situated at that point. These orthogonal planes further possess the property, that the internal pressures are perpendicular to them, and that one of them is the plane of maximum, and another the plane of minimum tension.

3. *Joint Planes.*

A joint plane is a surface of division in a rock, often remarkably smooth and clean cut, without the slickensides so often seen in faults, rarely accompanied by dislocation of the divided beds, and generally open from $\frac{1}{4}$ inch to 3 or 4 inches. A well-marked joint plane presents so striking a resemblance to the plane surface produced by crystallization, that this class of divisional planes in rocks has always been confidently appealed to by the advocates of the polar or crystalline theory of rock structure. In some cases I have no doubt that this resemblance is not imaginary, as for example in rock-masses of igneous origin, such as granites composed of uniform proportions of quartz, felspar, and mica, or hornblende. Such a rock-mass is truly a definite chemical compound, as much so as any mineral on a small scale, and therefore it is not surprising that it should sometimes present joints and planes intersecting at fixed angles, and characterized by all the properties of true crystalline faces. Such cases have come under my own observation, but not in sufficient numbers to entitle me to state any definite law, although I think much might be accomplished by systematic observations directed specially to this point. However this may be, there can be little doubt that the joints observed in a coarse conglomerate cannot be considered due to crystallization, which can scarcely be supposed to have acted upon a shingle formed of chance stones lying upon the beach of the Old Red Sandstone seas.

The joint surfaces in the conglomerate of Waterford are beautifully perfect, generally open 1 to 4 inches, nearly vertical, and when observed in the sea cliffs, giving rise to an almost columnar structure, in consequence of the sea having washed out huge rectangular prisms from the cliffs; these prismatic cavities and prominences being invariably bounded on two opposite sides by joint surfaces, and on the other two faces by the

cleavage surfaces which will presently be described. A fine example of this is shown in the Conglomerate Cliffs, eastward from Portally Head towards Oonarontia and Red Head: in this district the bedding is completely masked by the nearly vertical planes of joint and cleavage surfaces, which give a rudely prismatic and columnar appearance to the cliffs. Near Swiny Head this structure is remarkably well developed, and has produced a singular effect: one of the rude columns formed by the joint and cleavage surfaces has fallen partially forward, and presents an appearance, especially when seen from the sea, which resembles some of the old stone crosses found in many parts of Ireland.

One of the most striking circumstances connected with the joint surfaces in the conglomerate, is the fact that the large quartz pebbles, often 5 inches diameter, are cut clean across as if with a knife, forming a plane rigorously parallel to the general plane of the joint. The same remarkable fact is constantly observed in the joint surfaces of the carboniferous limestone all through Ireland; in which I have frequently observed a fossil cut in two by the joint plane, half being imbedded in each portion of the divided rock, and fitting accurately to each other when joined. In the cleavage planes the same circumstance is of universal occurrence all through the conglomerate of Waterford. According to my idea of the mechanical origin of these various planes, the cleavage surfaces are perpendicular to the lines of maximum force, and the joint surfaces perpendicular to the lines of minimum force, or maximum force of *shrinkage*, if I may use a barbarous word. The cleavage structure appears to have been first developed in the rock, and the jointed structure subsequently added by the shrinking of the rock-mass, consequent upon evaporation and drying. This shrinking and contraction of the mass would naturally show itself in planes perpendicular to the lines of minimum compression. That the whole rock-mass was pliant, and probably even soft, at the time the elevating forces were applied, appears from the distortion of fossil shells in shale beds of nearly the same age in the west of the County of Waterford, and all through the south of the County of Cork.

At first sight it might appear that the splitting of the hard quartz pebbles by the joint and cleavage planes was inconsistent with the supposition that the rock-mass was in a yielding condition at the time of the application of the forces, as it seems to indicate that these pebbles were held fast, as in a vice, by the hard matrix in which they were imbedded while the faces that split them were in action. I think, however, that independently of the conclusive argument derived from the distortion of the fossils, it is not difficult to understand how a pliant or yielding condition of the mass may have been a necessary condition for the development of this structure. Let us suppose the clay, sand, and mud of some landslip, soft, tough, and yielding, with its imbedded boulders and pebbles to represent the Old Red Sandstone conglomerate, acted on by external forces of compression, and by its own weight; at each point of the mass we shall have a plane of maximum pressure, and one of minimum pressure at right angles to it; and let us suppose a plane of maximum pressure to pass through several boulders or pebbles, which are unyielding substances imbedded in a viscous paste which presses them vari-

ously in different directions, but with a decided maximum in one particular direction. The effect of this pressure will be to cause relative motion among the particles of the paste, flattening them in a direction perpendicular to the line of force, and so causing cleavage structure, in the manner so admirably illustrated by Mr. SORBY's experiment on pipeclay and scales of iron, and by Mr. TYNDALL's experiment on wax. In the meantime the solid pebbles have not yielded sensibly, but show the effect of the enormous pressure they have been subjected to, by developing internally a *latent* cleaved structure, predisposing them to split most readily along planes perpendicular to the line of maximum force. In this manner I would account for the splitting of the quartz pebbles in the planes of cleavage; while, in the case of the joint planes which were formed subsequently, I conceive that the rock was consolidated, and the quartz pebbles held fast in their now hardened paste, while the shrinking took place perpendicular to the planes of minimum tension.

This mode of viewing the subject is confirmed by the fact, that in cleaved limestone districts, the distorted fossils are divided by the joints in well-cut planes, showing that the rock was consolidated when the joints were formed, although the distortion of the fossil proves that the rock was soft when the cleavage took place.

4. *Cleavage Planes.*

My attention was originally directed to the study of the physical geology of the red sandstone conglomerate of Waterford by the observation of two circumstances; the first of these was the rectangular prismatic appearance of the conglomerate cliffs already described; and the second was the detection of an inner structure of a peculiar character, which enabled me readily to distinguish the cleavage from the joint planes. I found that the coarse conglomerate had in many places acquired a platy or flaggy structure, the thickness of each plate varying from $\frac{1}{4}$th of an inch to 4 inches, the flat sides of the plate being perfect planes, cutting through the quartz pebbles in the most beautiful manner, and unaccompanied by any dislocation whatsoever. The moment I observed this peculiar structure in the conglomerate, I felt that I had found the key to the explanation of the physical structure of the whole district. I had before noticed the flaggy appearance assumed by the cleaved limestone of Cork and Kenmare, and the singular platy structure of many of the quartz rocks and grits of West Galway, and had referred them to incipient cleavage, rendered imperfect by coarseness of texture or want of viscosity; the possession of which latter quality appears to be the principal cause of the more perfect cleavage observed in slates and mud rocks in general; but I had never thought of finding cleavage in a coarse conglomerate. Having discovered the appearance of the cleavage proper to so coarse and heterogeneous a rock, I instantly determined to investigate the physical structure of the whole district with reference to this question. I determined with care the bearings and dips of 345 joint and cleavage planes along the coast, from Creadan Head to Brownstown Head and Rinishark, including about thirty observations inland made in quarries. In no case did I record an

observation without observing at least 20 square feet of the plane, and in many cases the surface exposed amounted to several hundred feet; and I may add, that I have not omitted a single observation made by me from the discussion contained in the following Tables.

Before proceeding to the discussion of the observations, I shall give my reasons for considering the planes of the flaggy structure observed by me, to be perpendicular to the lines of maximum force. I had already found in the distorted fossils of West Waterford conclusive arguments in favour of the view put forward by Mr. SHARPE, that the planes of cleavage were perpendicular to the line of maximum force; and before concluding that the platy or flaggy structure of the conglomerate was true cleavage, I was bound to show that its planes were perpendicular to the lines of greatest force. In the absence of fossils this could not be proved in the usual manner; but the following facts, ascertained by me, leave little doubt upon this important point.

Soon after I had first observed the flaggy structure of the cleavage planes of the conglomerate, I found that this structure was confined to planes having the general direction of the system (A), already noticed in speaking of faults, although it was occasionally observed in planes parallel to the system (A′). I never observed the flaggy structure in the systems C or C′; now, as the line of greatest force in a system of elevated beds must lie in the vertical plane, or nearly so, which contains the direction of the dip of the beds, and as the strike of the beds is intermediate between the systems A and A′, it is evident that we have a close approximation to SHARPE'S law; and, on the hypothesis already advanced, of two systems of elevating forces, perpendicular to A and A′ respectively, we have an exact conformity to this law.

I only found one locality in the whole district in which the cleaved flaggy structure had any other direction than either A or A′, and in this locality the deviation from the usual direction of cleavage constitutes a powerful argument in favour of the assertion, that the cleavage structure is perpendicular, or nearly so, to the line of maximum pressure.

A little north of Brownstown Head, on the side of Tramore Bay, near a place called Portoonaka Beg, and close to the Ordnance Levelling Mark No. 1, 1841, the rocks are beautifully cleaved with the peculiar flaggy or platy structure already so often described. The cleavage planes have a bearing of N. 12° W., and a dip 77° E. This plane corresponds with the system C, which ought to be a joint and not a cleavage plane; but it so happens, that in this locality there is considerable local contortion in the bedding of the conglomerate and thin shales; and throughout the entire area, in which the flaggy cleavage had this abnormal direction, I found the strike of the beds to have an azimuth or bearing within a few degrees of that of the cleavage. The bearing of the beds, in fact, ranges from N. 5° W. to N. 33° W., dip 10° N. Thus this apparent exception to the first mechanical law of cleavage turns out, on examination, to be a remarkable confirmation of it. I should add, that the flaggy structure at Portoonaka Beg divided the rock with great regularity into plates of 4 or 5 inches in thickness*.

* My attention was directed to this exception to the general direction of the flaggy cleavage by the

5. *Observations Tabulated.*

In the following Tables I have given the bearing and dip of every plane observed, and arranged them according to their geometrical grouping, taking the bearing of the plane as my standard of comparison.

I have also separated the planes east of Red Head from those west of Red Head, as this headland is the geological centre of elevation of the whole district, as I showed in the section on Faults.

Table I.

Joint Planes and Cleavage Surfaces, from Red Head Eastward to Creadan Head.

A. North of East.		A′. North of East.		C. West of North.		C′. West of North.	
Flat Rocks.		Flat Rocks.		Flat Rocks.		Flat Rocks.	
Bearing.	Dip.	Bearing.	Dip.	Bearing.	Dip.	Bearing.	Dip.
E. 10° N.	77° S.	E. 35° N.	88° S.	N. 10° W.	86° W.	N. 45° W.	74° E.
		— 33 —	88 —	— 10 —	80 —		
		— 27 —	72 N.				
		— 30 —	70 —				
Shanooan.		Shanooan.		Shanooan.		Shanooan.	
E. 17 N.	87 S.	E. 30 N.	75 S.	N. 15 W.	77 W.	N. 45 W.	75 W.
— 17 —	87 —	— 25 —	77 —			— 23 —	83 —
— 17 —	66 N.	— 26 —	82 —			— 20 —	90
— 10 —	76 —	— 20 —	84 —				
		— 20 —	63 N.				
		— 30 —	50 —				
		— 30 —	65 —				
		— 25 —	76 —				
		— 30 —	67 —				
		— 25 —	54 —				
		— 35 —	57 —				
Quarries.		Quarries.		Quarries.		Quarries.	
E. 10 N.	80 N.	E. 20 N.	72 N.	N. 7 W.	84 E.	N. 35 W.	67 W.
— 0 —	82 —	— 40 —	75 —	— 13 —	85 —		
— 0 —	87 —	— 35 —	90	— 17 —	82 W.		
— 0 —	83 —	— 35 —	70 S.				
— 0 —	86 —						
— 19 —	74 —						
— 5 —	85 —						
E. 8 S.	85 —						
— 5 N.	85 S.						
Harbour.		Harbour.				Harbour.	
E. 10 N.	90	E. 40 N.	90			N. 30 W.	85 W.
— 0 —	90	— 25 —	90			— 35 —	90
— 0 —		— 35 —	90				
— 0 —		— 35 —	75 S.				
— 15 —	90	— 40 —	80 N.				
		— 35 —	80 S.				
		— 25 —	65 N.				

Rev. Dr. Carson, Fellow of Trinity College, from whom I received valuable aid in my somewhat laborious survey of the County of Waterford conglomerate.

TABLE I. (continued).

A. North of East.		A′. North of East.		C. West of North.		C′. West of North.	
E. of Harbour.		E. of Harbour.		E. of Harbour.		E. of Harbour.	
Bearing.	Dip.	Bearing.	Dip.	Bearing.	Dip.	Bearing.	Dip.
E. 5° N.	88° S.	E. 35° N.	87° N.	N. 5° W.	87° E.	N. 30° W.	70° W.
— 10 —	85 —	— 30 —	87 —	— 0 —	90	— 35 —	90
— 10 —	85 N.	— 40 —	87 —	— 5 —			
— 10 —	60 —	— 40 —	90	— 5 —	90		
— 5 —	90	— 25 —	90	— 0 —	90		
— 12 —	84 N.	— 28 —	90	— 10 —	90		
— 10 —	90	— 40 —	67 N.	— 10 —	70 E.		
		— 30 —	70 —				
		— 30 —	76 —				
Dunmore.		Dunmore.		Dunmore.		Dunmore.	
E. 0 N.	90	E. 33 N.	90	N. 5 W.	90	N. 25 W.	
		— 35 —	90	— 10 —	90		
		— 35 —	90	— 5 —	90		
		— 25 —	90	— 5 —	90		
		— 40 —	70 N.				
Cathedral Rocks.		Cathedral Rocks.		Cathedral Rocks.		Cathedral Rocks.	
E. 12 N.	85 S.	E. 35 N.	78 S.	N. 8 W.	77 E.	N. 30 W.	85 E.
— 10 —	90	— 35 —	77 —	— 10 —	77 —	— 35 —	60 —
		— 40 —	80 —	— 10 —	90	— 30 —	62 —
		— 35 —	90	— 6 —	90		
		— 36 —		— 5 —	90		
		— 37 —		— 10 —	67 W.		
		— 35 —	90				
		— 35 —	80 S.				
Ardnamult.		Ardnamult.		Ardnamult.		Ardnamult.	
E. 10 N.		E. 35 N.	85 S.	N. 0 W.	90	N. 40 W.	
		— 45 —		— 10 —	90	— 35 —	90
		— 35 —				— 45 —	59 W.
		— 40 —	90			— 35 —	80 —
		— 40 —	90				
		— 35 —	90				
		— 40 —	70 S.				
		— 35 —	90				
		— 35 —	80 N.				
Creadan.		Creadan.		Creadan.		Creadan.	
E. 10 N.	90	E. 45 N.	90			N. 30 W.	90
— 10 —	90	— 30 —	90			— 35 —	90
— 10 —		— 35 —					
— 0 —	90						
251÷34		1990÷60		191÷25		638÷19	
7° 23′ North of East.		33° 10′ North of East.		7° 38′ West of North.		33° 35′ West of North.	

System A.

The system A contains 34 observations to the east of Red Head; of these

14 planes are vertical.
13 dip North at 80° average.
7 dip South at 85° average.

The average bearing of the whole system is 7° 23′ North of East.

This bearing of the cleavage planes is nearly coïncident with that of the same system of faults, viz. 7° 30′ North of East.

This may be considered as an east and west system, so far as strike or bearing is concerned; but it is divisible into two systems with respect to dip.

System A′.

The system A′ contains 60 observations; of these

24 planes are vertical.
21 dip North at 71° average.
15 dip South at 79° average.

The average bearing of the whole system is 33° 10′ North of East, which agrees with the bearing of the system of faults called A′, in p. 335, viz. 34° 22′ North of East. This system, A′, is the second east and west system, and the cleavage planes are sometimes found in this direction, though more generally in the direction A. It is to be observed of both these systems, that the planes dip to the north at a smaller angle than to the south.

System C.

This system contains twenty-five observations; of these

14 planes are vertical.
6 dip East at 80° average.
5 dip West at 78° average.

The average bearing of this system of planes, which is conjugate to the system (A), is 7° 38′ West of North.

System C′.

This system, east of Red Head, consists of nineteen observed planes; of which

8 are vertical.
4 dip East at 70° average.
7 dip West at 74° average.

The average bearing of this system is 33° 35′ West of North.

The following Table contains the planes belonging to the conjugate systems A and C, and also A′ and C′, observed westward of Red Head; where the faults are more numerous than to the east, and their downthrows in the opposite direction.

Table II.

Joint Planes and Cleavage Surfaces, from Red Head Westward to Brownstown Head.

A. North of East.		A′. North of East.		C. West of North.		C′. West of North.	
Red Head to Bishop's Cave.		Red Head to Bishop's Cave.		Red Head to Bishop's Cave.		Red Head to Bishop's Cave.	
Bearing.	Dip.	Bearing.	Dip.	Bearing.	Dip.	Bearing.	Dip.
E. 15° N.	83° S.	E. 25° N.	83° S.	N. 10° W.	70° E.	N. 35° W.	53° W.
— 10 —	55 N.	— 25 —	80 —	— 10 —	83 —	— 32 —	66 E.
— 5 —	85 S.	— 25 —	82 —	— 5 —	74 —	— 30 —	86 W.
— 10 —	80 —	— 30 —	80 —	— 5 —	85 —	— 30 —	75 —
— 10 —	74 N.	— 35 —	87 —	— 5 —	90 —	— 25 —	72 E.
— 5 —	65 —	— 35 —	83 —	— 5 —		— 40 —	
— 0 —	70 —	— 35 —	70 N.				
— 5 —	78 —	— 35 —	74 —				
— 5 —	65 —	— 35 —	75 —				
— 5 —	90	— 35 —	90				
		— 35 —	65 N.				
		— 35 —	80 S.				
		— 35 —	76 —				
		— 35 —					
		— 35 —	90				
		— 35 —	80 S.				
		— 35 —	90				
		— 45 —	70 S.				
		— 35 —	80 —				
		— 35 —	80 —				
		— 35 —	90				
		— 20 —	80 S.				
Bishop's Cave to Portally.		Bishop's Cave to Portally.		Bishop's Cave to Portally.		Bishop's Cave to Portally.	
E. 15 N.	84 S.	E. 35 N.	90	N. 5 W.	90	N. 25 W.	87 W.
— 15 —	86 —	— 35 —	90	— 5 —	90	— 40 —	74 E.
— 10 —	85 —	— 30 —	90	— 5 —	90		
— 10 —	87 N.	— 35 —	80 S.	— 5 —	90		
— 10 —	87 —	— 30 —	70 —	— 7 —	86 W.		
— 5 —	68 —	— 35 —	85 —	— 10 —	88 E.		
— 15 —	85 S.	— 40 —	80 —	— 5 —	90		
— 15 —	90	— 30 —	90	— 5 —			
— 10 —	90	— 33 —	85 N.	— 6 —	85 W.		
— 5 —	90	— 33 —	90				
— 15 —	90	— 30 —	90				
— 10 —		— 30 —	85 S.				
Portally to Old Ship's Cove.		Portally to Old Ship's Cove.		Portally to Old Ship's Cove.		Portally to Old Ship's Cove.	
E. 10 N.	85 S.	E. 30 N.	90	N. 0 W.	90	N. 45 W.	90
— 10 —	90	— 30 —	75 N.	— 10 —	90	— 45 —	85 W
— 10 —	90	— 33 —	90	— 15 —	90	— 35 —	75 E.
— 0 —	90	— 35 —	90	— 0 —	90	— 35 —	80 —
— 5 —	90	— 30 —	90			— 30 —	90
— 10 —	90	— 30 —	70 N.			— 30 —	90
— 10 —	90	— 35 —	80 S.			— 40 —	90
— 0 —	60 N.	— 35 —	66 N.			— 40 —	80 E.
— 0 —	70 —	— 30 —				— 35 —	80 —
— 5 —	60 —					— 45 —	90
— 10 —	90						
— 10 —	90						

TABLE II. (continued).

A. North of East.		A′. North of East.		C. West of North.		C′. West of North.	
Old Ship's Cove to Rathmoylan Cove.		Old Ship's Cove to Rathmoylan Cove.		Old Ship's Cove to Rathmoylan Cove.		Old Ship's Cove to Rathmoylan Cove.	
Bearing.	Dip.	Bearing.	Dip.	Bearing.	Dip.	Bearing.	Dip.
E. 10° N.	90°	E. 20° N.	90°	N. 5° W.	90°	N. 35° W.	90°
— 10 —	90	— 20 —	90	— 15 —	90	— 40 —	90
— 15 —	90	— 25 —	90	— 0 —	75 W.	— 40 —	90
— 15 —	70 S.	— 35 —	90			— 40 —	90
		— 35 —	85 N.			— 45 —	86 W.
		— 30 —	90				
		— 40 —					
		— 45 —	90				
		— 35 —	80 N.				
		— 37 —	90				
		— 40 —	87 S.				
		— 35 —	87 N.				
		— 43 —	87 S.				
		— 45 —	87 —				
		— 45 —	85 —				
		— 35 —	55 N.				
		— 35 —	60 —				
Brownstown Head District.		Brownstown Head District.		Brownstown Head District.		Brownstown Head District.	
E. 7 N.	60 N.	E. 35 N.	90	N. 12 W.	77 E.	N. 40 W.	90
— 7 —	60 —	— 33 —	66 N.	— 0	90	— 45 —	90
— 15 —	90	— 33 —	60 —			— 30 —	75 E.
— 5 —	66 N.	— 45 —	80 —			— 33 —	60 W.
— 0 —	75 —	— 33 —	60 —			— 40 —	90
— 3 S.	90	— 35 —	70 —				
— 12 N.	80 N.	— 32 —	90				
— 0 —	60 —	— 32 —	90				
— 0 —	90	— 33 —	90				
		— 45 —	90				
		— 32 —	70 S.				
		— 32 —	70 N.				
		— 35 —	90				
		— 37 —	80 S.				
		— 30 —	80 —				
378÷47		2536÷75		150÷24		1025÷28	
8° 2′ North of East.		33° 48′ North of East.		6° 15′ West of North.		36° 36′ West of North.	

System A.

This system, to the west of Red Head, consists of 47 planes; of which

20 are vertical.
18 dip North at 69° average.
9 dip South at 82° average.

It is to be observed here, as before, that the northern dip of the planes is less than the southern.

The average bearing of system A, west of Red Head, is 8° 2′ North of East.

System A′.

This system is very strongly marked at many places to the west of Red Head. It contains 75 planes observed; of which

30 are vertical.
19 dip North at 71° average.
26 dip South at 81° average.

The northern dip of these planes is also less than the southern.

The average bearing of this system is 33° 48′ North of East, which coincides remarkably well with the bearing of the most important system of faults in the district, viz. A′= 34° 22′ North of East.

System C.

This system contains 24 observed planes; of which

15 are vertical.
6 dip East at 79° average.
3 dip West at 82° average.

The average bearing of this system is 6° 15′ West of North.

System C′.

This system, west of Red Head, contains 28 observed planes; of which

13 are vertical.
8 dip East at 75° average.
7 dip West at 76° average.

This system bears 36° 36′ West of North; and it is to be observed that the easterly and westerly dips of C and C′ West of Red Head are more nearly equal than the northerly and southerly dips of A and A′, a fact which also appears from the observations East of Red Head.

Besides the planes already recorded, which belong to the conjugate systems A, C, and A′, C′, there were several others, which I have endeavoured to tabulate as follows:—

Exceptional Joint Planes.

(A″.)

Bearing.	Dip.	Locality.
E. 25° S.	80° N.	Creadan Head.
— 30 —		Creadan Head.
— 25 —	80 S.	Creadan Head.
— 25 —	80 —	Creadan Head.
— 30 —	70 —	Creadan Head.
— 20 —	90	Creadan Head.
— 30 —	85 S.	Dunmore Harbour.
— 35 —	90	Dunmore Harbour.
— 35 —	82 N.	Portally, West.
— 37 —	85 —	Portally, West.
— 30 —	85 —	Portally, West.
— 25 —	78 —	Remarkable outlying rock off eastern entrance to Portally Cove.
— 30 —	90	Old Ship's Cove.
— 40 —	90	Beenlea Head.
427÷14		
30° 30′ South of East.		

(C″.)

Bearing.	Dip.	Locality.
N. 25° E.	90°	Creadan Head.
— 20 —		Creadan Head.
— 20 —		Creadan Head.
— 25 —		Creadan Head.
— 30 —	77 E.	Old Ship's Cove.
— 30 —	90	Old Ship's Cove.
— 30 —	90	Old Ship's Cove.
— 25 —	82 E.	Swiny Head.
— 40 —	70 —	Rathmoylan Cove.
— 40 —	90	Rathmoylan Cove.
— 40 —	90	Rathmoylan Cove.
— 25 —	68 W.	Quarry inland.
350÷12		
29° 10′ East of North.		

(C'''.)

Bearing.	Dip.	Locality.
N. 10° E.	60° E.	Creadan Head.
— 10 —	90	Stone Cross.
— 7 —	77 E.	Rathmoylan Cove.
— 10 —	90	Rathmoylan Cove.
— 10 —	77 E.	Rathmoylan Cove.
— 10 —	90	Rathmoylan Cove.
57÷6		
9° 30′ East of North.		

I find in my note-book one observation of a bearing E. 10° S. made by me at Creadan Cove; it appears to be the solitary representative observed by me of the bearing rectangular and conjugate to that of C'''. Although it is a single observation, I believe it affords evidence (although not strong) of the probable existence in this district of a *fourth* system of forces having acted upon the conglomerate beds.

Total Number of Observations.

A.	A′.	A″.	A‴.	C.	C′.	C″.	C‴.
81	135	14	1	49	47	12	6
Total number of Planes observed = 345							

From the preceding discussion of the planes of structure not belonging to the two principal conjugate systems of the district, I feel little hesitation in coming to the conclusion that there was at least one more system of forces at work, in producing the final structure of the Old Red Sandstone conglomerate of the South East of the County of Waterford.

The bearings of this system are,

30° 30′ South of East,
29° 10′ East of North.

There is also evidence, although not so good, of another conjugate system, bearing 9° or 10° East of North and South of East.

A summary of the four conjugate systems is here added, showing how nearly perpendicular their component bearings are. I consider the first system to have acted first on the district, developing the greater part of the cleavage structure; and that the second system was subsequent to the first, but probably produced by even greater forces; of the third and fourth systems I know nothing beyond their existence; the key to them may possibly be found in other districts.

First Conjugate System.

A.	629° ÷ 81	7° 46′ North of East.
C.	341 ÷ 49	6 57 West of North.
Angle between Axes from East to North = 89° 11′		

Second Conjugate System.

A′.	4526° ÷ 135	33° 31′ North of East.
C′.	1663 ÷ 47	35 23 West of North.
Angle between Axes from East to North = 91° 52′		

Third Conjugate System.

A″.	427° ÷ 14	30° 30′ South of East.
C″.	350 ÷ 12	29 10 East of North.
Angle between Axes (North and East) = 91° 20′		

Fourth Conjugate System.

A‴.	One observation.	10° ′ South of East.
C‴.	57° ÷ 6	9 30 East of North.
Angle between North and East Axes = 90° 30′		

Note added after the reading of the Paper.

Throughout this paper I have assumed the perpendicularity of the cleavage planes to the lines of maximum force. This assumption I have made on evidence quite distinct from the facts mentioned with relation to the perpendicularity of the horizontal traces of the cleavage and joint planes to each other. I believe the proper evidence of the perpendicularity of cleavage to the lines of maximum force must be sought for in fossiliferous slate districts, where the distortion of the fossil enables us to determine the exact position of the line of maximum force, and consequently its relation to the plane of cleavage.

The evidence of fossils is wanting in the conglomerate of the County of Waterford, and we are consequently unable to determine the precise lines of maximum force, except so far as the inclination of the beds gives us information.

Having established by observation the existence of conjugate systems of planes, I have drawn mechanical inferences, founded on the assumption of the perpendicularity of cleavage to the lines of maximum force; and these inferences have not, of course, the same degree of evidence in their favour that the geometrical relations of the cleavage and joint planes have.

In fact, the geometrical relations of these planes are observed facts, while the mechanical inferences have only the probability (in my opinion a high one) of the law assumed on other evidence.